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# IoT Based Weather Monitoring System using ESP32 Microcontroller

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**Abstract:** *Weather prediction today has become unreliable due to constant changes in atmosphere compositions, unreliable data quality or low quality data being fed to operational models. To address this issue, this research paper proposes a solution to this problem by developing a Smart IoT based Weather Monitoring System powered by ESP-32 WROOM DEVKIT microcontroller that integrates BME-280 Sensor for temperature, humidity, sea level pressure; MQ-135 Gas Sensor to measure approximate Air Quality Index, ML8511 to measure approximate UV Intensity, Rain sensor module for detecting rain and three LEDs for indicating suitability of outdoor activities. The data is collected and displayed on a custom HTML Web Dashboard with real time data and charts; data is sent to Google sheets and e-mail alerts are sent. The web dashboard, Google sheets are publicly accessible and e-mail alerts are sent to all members living in the community. The prototype demonstrated functional accuracy within ±5% for temperature and humidity and ±15% for air quality and UV Index compared to reference datasets from official channels [8-10]..*

**Keywords***:* IoT, Weather monitoring, Sensor, Microcontroller, UV-intensity

## I. INTRODUCTION

Rapid urbanization, deforestation and various kinds of pollution in the past few decades have led to a growing concern about environmental monitoring and weather prediction accuracy. Predicting accurate weather plays a crucial role in agriculture, disaster management, transportation and public health. Despite its importance, weather prediction in remote areas is not always completely reliable and is difficult to access too. The Indian Meteorological Department (IMD) provides reliable forecasts but it's mostly generalized over a large geographical area, which limits its accuracy for analysis in small towns and villages.

With the rise of IoT (Internet of things), it has become possible to develop compact, affordable and Smart weather monitoring systems that can sense and report local environmental data. These systems can be deployed at a community level to monitor the environmental conditions of the specific locality, which can help people to get real time weather data on their mobile phones. Such systems can also be deployed at schools and at instituitons for research purposes so that students and researchers can perform the study of localized environmental data and analyse various data and trends. This study focuses on a cost- effective, community-deployable IoT weather station designed as an alternative of official meteorological data through localized environmental measurements[4][5]. In this study, an IoT-based weather monitoring system was designed and implemented. The project consisted of an ESP-32 WROOM DEVKIT V1 microcontroller along with MQ-135, ML8511, a rain sensor module, three leds (green, yellow and red) for air quality, UV index and rainfall detection respectively, a BME280 sensor was also used to measure temperature, humidity and sea level pressure. The device continuously measured data for 3 days, displayed readings of various data in a web dashboard, sent the data to Google Sheets and recorded it with timestamp, sent an e-mail alert to the user and also displayed data in Blynk IoT platform.

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**Objectives**

- The system will combine ESP32-WROOM DEVKIT module with affordable hardware to construct the weather monitoring system.
- A real time data monitoring system shall be built by integrating BME280, ML8511, MQ-135, Rain Sensor along with three LED's to allow display of data on various interfaces
- The system will deliver monitored sensor readings through WiFi connection and let anyone track the inputs from any location

## II. METODOLOGY

### 2.1 Hardware Components

| **Component** | **Description** | **Function** |
|---|---|---|
| ESP32 WROOM DEVKIT V1 | Microcontroller with and built in Wi-Fi and Bluetooth connectivity | Serves as the main control unit, gets sensor data and transmits it using Wi-Fi. |
| BME 280 Sensor | Multifunctional environmental sensor measuring temperature, humidity and sea level pressure | Measures temperature, sea level pressure and humidity. |
| MQ-135 Sensor | Multi-purpose gas sensor used to detect and monitor a wide range of harmful gases in the air, such as ammonia, nitrogen dioxide, alcohol, carbon dioxide and smoke[7] | Measure presence of carbon dioxide, ammonia, nitrogen dioxide, alcohol in air and used to estimate AQI (Air Quality Index) |
| ML8511 Sensor | Photo-diode base UV index sensor | Detects UV radiation intensity and estimates UV Index |
| Rain Sensor | Resistive sensor for detecting rainfall | Determines presence and intensity of rainfall |
| LED Indicators | Green, Red and Yellow leds | Used for showing environmental conditions suitability for outdoor activities (Good, Moderate and Bad) |

**SOFTWARE COMPONENTS**

Firmware Development

Arduino IDE was used to develop the Firmware, the code was designed to read sensor data, connect to Wi-Fi, send data to Google Sheets, send E-mail alerts. The firmware was designed to minimize data loss during Wi-Fi transmission and ensure time stamp synchronization using the NTP Client.

The code integrates data from multiple sensors that are as follows:

- BME280 for temperature, humidity and pressure
- MQ135 for estimating Air Quality Index (AQI)
- ML8511 (UV Sensor) for estimating UV Index
- Rain Sensor module for detecting rain

The data from these sensors is processed in real time, and estimation of Air Quality and UV Index is done and then transmitted to Google Sheets for data logging, a web dashboard is deployed using HTML and Charts.js.

The firmware includes:

- Sensor Calibration logic for MQ-135 and ML8511 Sensors
- Automatic error Handling and baseline correction
- LED logic for showing suitability of outdoor activities (Red- Not suitable, Green-Suitable, Yellow- Moderately suitable)

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- Time synchronization using NTPClient
- Periodic upload using HTTPClient

**SENSOR CALIBRATION AND AVERAGING**

**MQ-135 GAS SENSOR (AIR QUALITY MEASUREMENT)**

The MQ-135 sensor was used to measure the concentration of various gases that contribute to air pollution, including ammonia, nitrogen oxides, alcohols, benzene, and carbon dioxide.

However, the sensor does not directly output an Air Quality Index (AQI). Instead, it provides an analog voltage corresponding to the sensor resistance, which varies with gas concentration.

To convert the sensor output into meaningful data:

The analog voltage ($V_{out}$) was read using the ESP32's ADC (12-bit resolution).

The sensor resistance ($R_S$) was calculated using the formula: [1][3]

$$R_s = R_L \text{ x } (\frac{V_{cc}}{V_{out}} - 1)$$

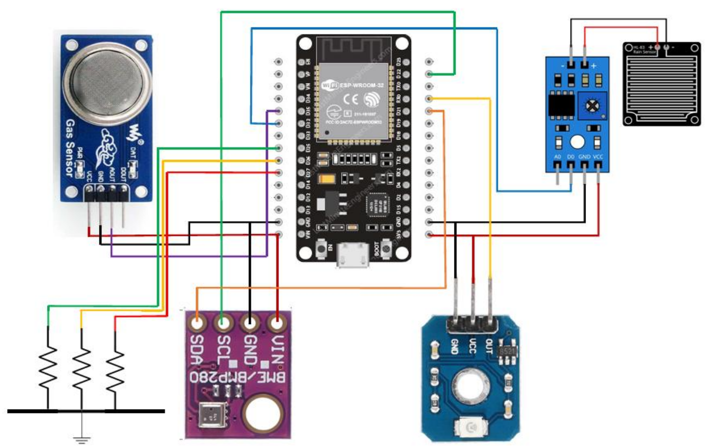


Figure-1: Circuit Diagram

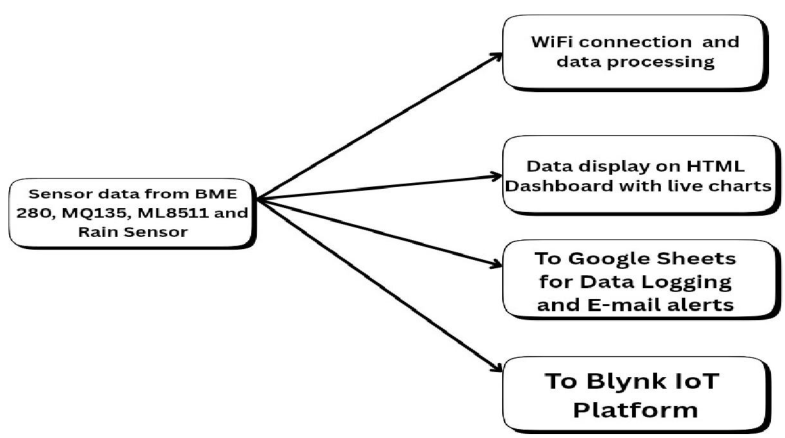


Figure-2: Working of the model

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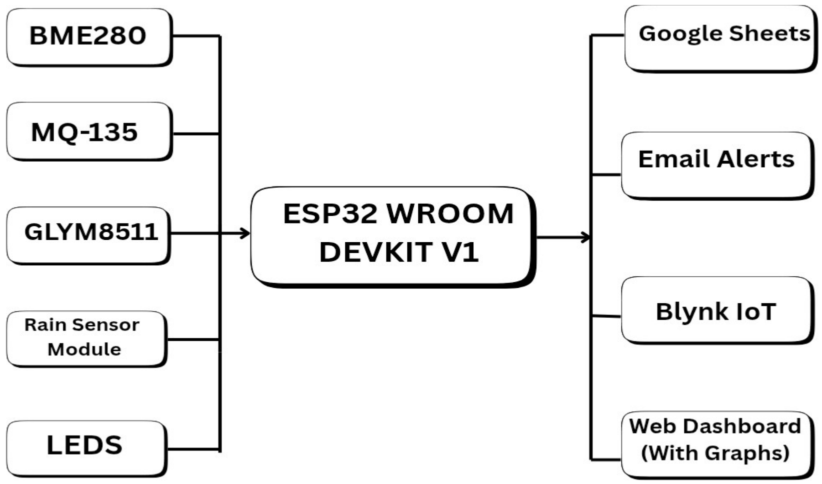


Figure-3: Project Overview

A reference resistance ($R_O$) was determined by measuring ($R_S$) under clean air conditions. In this project, ($R_O$) was found to be approximately 75.4kΩ.

The ratio ($\frac{R_S}{R_O}$) was then used to estimate the pollutant level, since the MQ-135's sensitivity to $R_O$ gases follows a logarithmic relationship.

The readings were stabilized by averaging multiple samples (around 15-20) taken over short intervals. This averaging minimized noise and fluctuations cause by environmental disturbances, ensuring smoother and more reliable AQI output.

ML8511 UV Sensor (Ultraviolet Radiation Measurement)

The ML8511 sensor gives an output analog voltage proportional to the intensity of ultraviolet radiation falling on it. However, the analog voltage output is affected by ambient light and circuit noise, to mitigate this a careful calibration was performed to establish a reference (baseline) and scaling factor.

The calibration steps included:

Measuring the baseline voltage ($V_{baseline}$) indoors under no UV exposure, the value recorded was 0.99V.

Measuring the analog voltage values under known conditions i.e. shade, bulb light and direct sunlight, which yielded approximately 0.6V, 1.76V and 1.82V respectively

The difference in voltage ($V_{UV} - V_{baseline}$) was mapped to the standard UV Scale which is (0-11). Using a proportional conversion formula [2]

$UV_{Index} = (V_{UV} - V_{baseline})$ x K, K= 14-15 UV Index per volt

(based on ROHM'sdatasheet and Adafruit's calibration)

Both the MQ-135 and ML8511 Sensors can exhibit random variations due to analog noise, temperature drift and minor voltage instability, to counter this; a software-based averaging mechanism was implemented:

Each sensor data was read multiple times in quick succession.

The mean of the data was used as the final value for display and transmission.

Best possible efforts were made to make the sensor data output reliable.

## III. RESULT AND DISCUSSION

**3.1 Data Collection -** The system was deployed outdoors between 3:00PM and 4:00PM for real time environmental monitoring. Data was recorded from the ESP32 microcontroller and recorded in HTML Web Dashboard, the Blynk IoT Platform and automatically logged in on Google sheets. The recorded datasets exhibited consistent temporary variations aligned with diurnal environmental changes. However, minor deviations from reference data were observed which can be attributed to sensor non-linearity and localized micro-climatic efforts.

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### *3.2 Recorded Outputs*

**Weather Dashboard**

| Timestamp | Temperature (A°C) | Humidity (%) | Pressure (hPa) | UV Index | Air Quality (AQI) |
|---|---|---|---|---|---|
| 4:21:20 PM | 34.7 | 39.7 | 1013.4 | 1.4 | 92.4 |
| 4:11:20 PM | 35.8 | 37.3 | 1013.4 | 1.1 | 93.2 |
| 4:01:20 PM | 35.5 | 37.6 | 1013.4 | 1.3 | 92.6 |
| 3:51:21 PM | 36 | 37.4 | 1013.3 | 1.4 | 93.5 |
| 3:41:21 PM | 36.2 | 36.2 | 1013.3 | 1.4 | 92.5 |
| 3:31:21 PM | 36.5 | 35.3 | 1013.3 | 1.2 | 92.7 |
| 3:21:20 PM | 36.4 | 35 | 1013.3 | 1.3 | 87.6 |
| 3:11:21 PM | 36.9 | 34.6 | 1013.4 | 1.5 | 97.5 |
| 3:01:20 PM | 37.5 | 35.3 | 1013.5 | 1.4 | 101.4 |

Table-1: Data recorded in the form of a table in the HTML Web Dashboard

Fig 2 ( Temperature graph on dashboard)

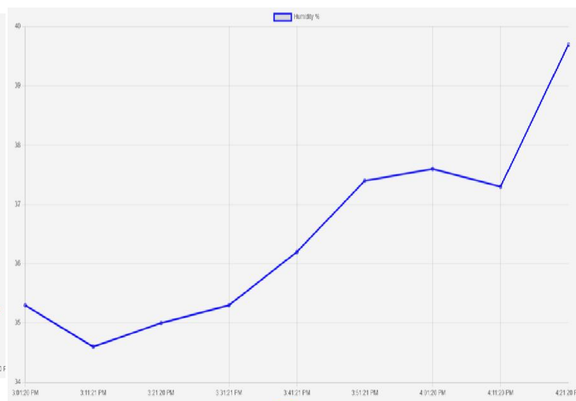

Fig 3 (Humidity graph on dashboard)

Fig 4 (UV Index graph on dashboard)

Fig 5 (AQI graph on dashboard)



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Weather Station Data

| | Time | Temp. | Humidity | Pressure | Air Quality | UV Index | Rain |
|---|---|---|---|---|---|---|---|
| 8288 | 15:07:53 | 36.92 | 34.82 | 1013.47 | 97.73 | 1.63 | 1 |
| 8289 | 15:17:57 | 36.69 | 34.16 | 1013.29 | 93.87 | 1.21 | 1 |
| 8290 | 15:28:01 | 36.88 | 34.48 | 1013.33 | 93.23 | 1.27 | 1 |
| 8291 | 15:38:04 | 36.25 | 35.43 | 1013.3 | 92.16 | 1.42 | 1 |
| 8292 | 15:48:08 | 36.04 | 36.09 | 1013.32 | 89.01 | 1.34 | 1 |
| 8293 | 15:58:12 | 36.3 | 36.58 | 1013.36 | 94.19 | 1.21 | 1 |
| 8294 | 16:08:17 | 35.59 | 37.87 | 1013.39 | 93.36 | 1.21 | 1 |
| 8295 | 16:18:23 | 35.18 | 38.81 | 1013.41 | 92.72 | 1.12 | 1 |
| 8296 | 16:28:28 | 34.35 | 40.55 | 1013.49 | 93.33 | 1.47 | 1 |
| 8297 | 16:38:31 | 34.26 | 41.24 | 1013.47 | 94.8 | 1.5 | 1 |
| 8298 | 16:48:35 | 33.62 | 42.62 | 1013.44 | 94.93 | 1.48 | 1 |
| 8299 | 16:58:38 | 33.25 | 43.67 | 1013.4 | 95.27 | 1.43 | 1 |
| 8300 | | | | | | | |

Although all each data source was synchronized through the system's internal NTP client, there was slight error in the code which led to mismatch in timings of Google Sheets logging.

Fig 6 (Google Sheets Platform)

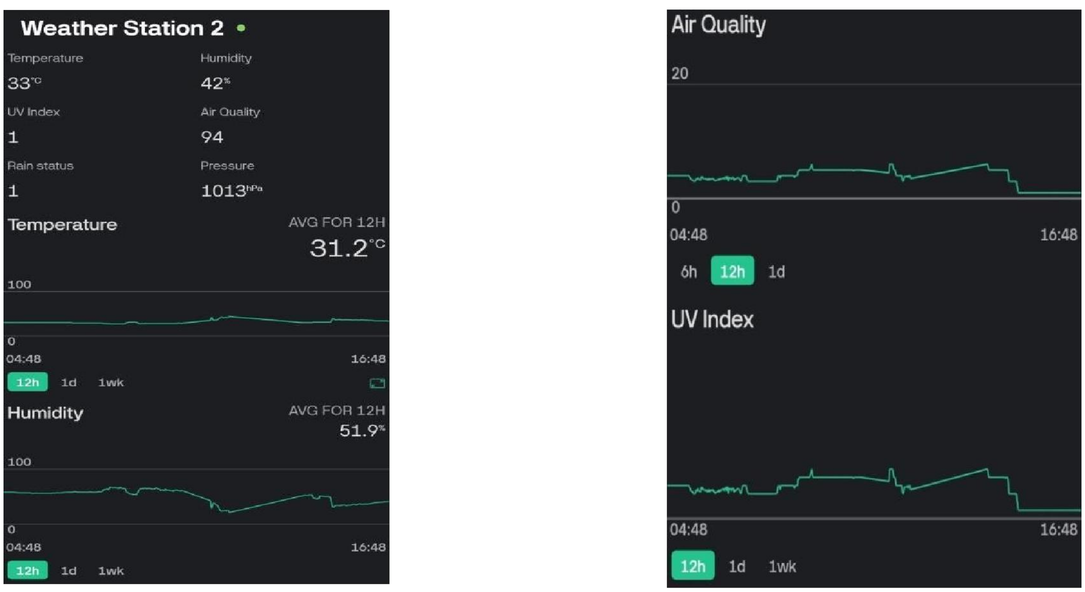


Fig 7 (Blynk IoT Platform)

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Weather Station Alert 🚨 Inbox ×

sameer08.uddin@gmail.com
to me

Time: 16:00:02
Temp: 30.92°C
Humidity: 57.28%
Pressure: 1011.69 hPa
Air Quality: 0
UV Index: 8.89
Rain: 1

⚠️ Issues:
☀️ High UV Index: 8.89

The system was designed to send email alerts every 10 minutes, the feature has been implemented in the code but was not fully validated in the testing phase due to network and API constraints. This is a sample alert from 2 days earlier

Fig 8 Email Alerts

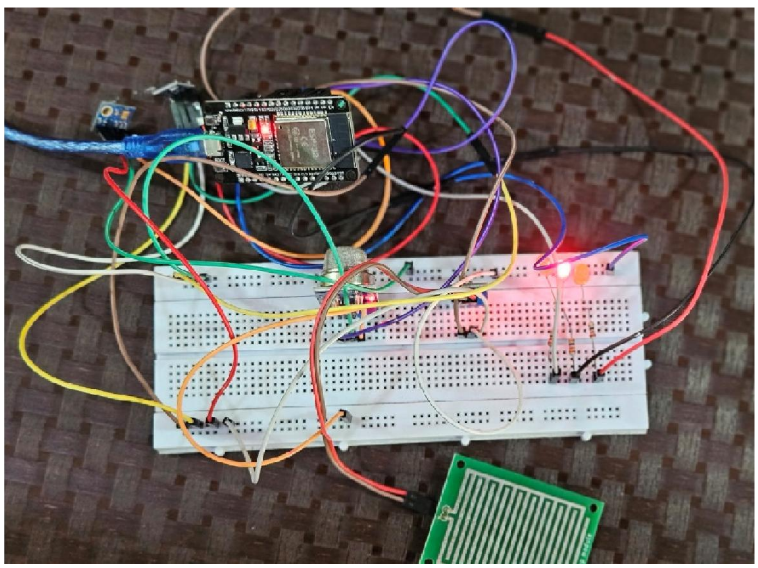

Fig 9 (Working Model)

| Time | | Temp | Weather | Wind | Humidity | Barometer | Visibility |
|---|---|---|---|---|---|---|---|
| 15:00 | | 31 °C | Scattered clouds. | 6 km/h | 55% | 1009 mbar | 5 km |
| 15:30 | | 31 °C | Scattered clouds. | 7 km/h | 52% | 1009 mbar | 5 km |
| 16:00 | | 31 °C | Scattered clouds. | 6 km/h | 55% | 1009 mbar | 5 km |
| 16:30 | | 31 °C | Scattered clouds. | 6 km/h | 55% | 1009 mbar | 4 km |

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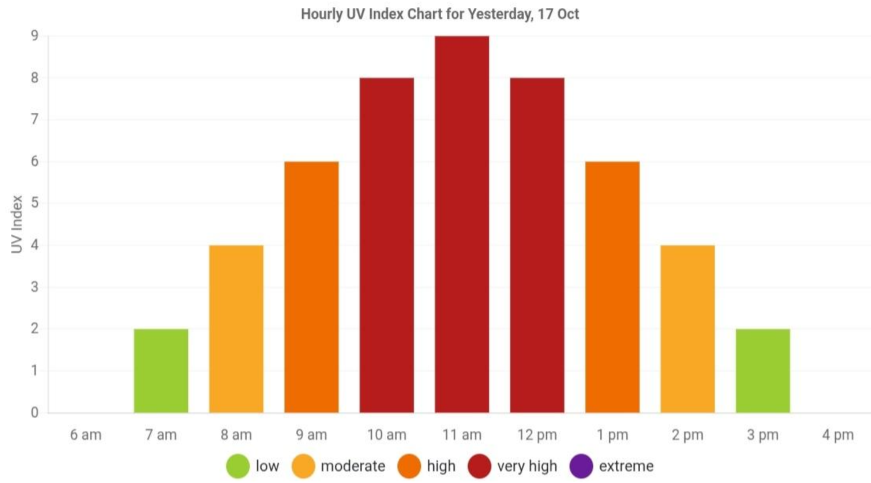

Fig 9 (Weather condition and UV Index from official sources) [8][9]

## IV. CONCLUSION

The proposed IoT based environmental monitoring system was successfully designed and implemented using the ESP-32 microcontroller integrated with the BME280, MQ-135, ML8511, and rain sensors. The system measures and transmits real-time data on temperature, humidity, air pressure, air quality and ultra violet radiation and visualizes through a dynamic HTML Web Dashboard with graphs. Continuous data logging to Blynk IoT platform and Google sheets was implemented for long-term monitoring purposes.

While the recorded data demonstrated general consistency with the official sources[8][9] data, minor deviations were observed too. These inconsistencies can be attributed to the sensors limitations such as non-linear analog response, cross-sensitivity with temperature and humidity (especially UV Sensor) and environmental noise all of which are common in low-cost air and UV sensors.

Nevertheless, the data from the system validate the core objective of this study– to establish a low-cost, accessible framework for local data collection. The readings confirm that with proper calibration, averaging and advanced data correction algorithms, such systems can serve as reliable alternatives for educational, research and basic environmental research analysis.

## LIMITATIONS

- Although the developed system successfully monitored multiple parameters, several limitations were observed during experimentation and data analysis, they are as following:
- The sensor precision of low-cost modules such as MQ135 and ML8511 is inherently limited compare to certified meteorological instruments which are worth lakhs in rupees. These sensor's analog values tend to show non-linear characteristics, temperature and humidity dependence and sensitivity to other gases, the MQ-135 covers a limited range of gases such as carbon dioxide, alcohol, ammonia, sulphides etc. it does not exhibit the ability to measure ppm values directly.
- The factors such as airflow, sensor placement and lack of active air circulation and controlled reference conditions may have influenced the inaccuracy of gas concentration and UV Index measurements.
- The ADC resolution and electrical noise on the ESP32 board may have caused small fluctuations in analog readings, particularly under unstable Wi-Fi transmission or power supply variations
- Finally the discrepancies between the recorded data and external sources can be attributed to differences in geographical locations, differences in calibration methods and sensor response times.

**FUTURE SCOPE OF WORK**

- Due to the model's various limitations in predicting full-fledged weather data future improvements to this work that can enhance the working and scope of this model are as follows:
- Enhanced Calibration and Error Modelling
  Future improvements can incorporate multivariate calibration models or machine learning regression techniques to reduce inaccuracies with reference to official weather data. Deploying polynomial fitting could significantly refine the sensor response curves.
- Sensor Array Expansion
  Integrating high precision sensors, including PM2.5/PM10 particulate sensors, NDIR carbon dioxide modules, UV Sensors can improve sensor readings. Adding new sensors such as an anemometer which can give direction of wind, an LDR Sensor for detecting sunrise and sunset time can be included to increase the number of parameters being measured.
- Energy Optimization and Remote Deployment
  Incorporating solar panels will make the device power independent and make it transmit data without any power shortage concerns, it can be useful for long-term outdoor autonomous operation particularly in remote areas which have unreliable source of power.
- Data Correlation and Scientific use
  The collected data can be uploaded to Google Firebase, AWS Cloud or ThingSpeak to study localized microclimatic patterns and air pollution parameters fostering in a community-led research. Work can also be done to focus on developing statistical data modelling and pattern recognition models to correlate sensor data with official government data for correction and benchmarking.

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